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DISTRIBUTION AND ABUNDANCE OF *PINNOTHERES MACULATUS* SAY IN BOGUE SOUND, NORTH CAROLINA

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The pea crab, *Pinnotheres maculatus* Say, is a symbiont found in the mantle cavity of many bivalve molluscs. The bay scallop, *Argopecten irradians concentricus* (Say), is its most common host in the inland waters of North Carolina.

Observations on the biology of *P. maculatus* are limited to a list of hosts in which the crab are found (Williams, 1965), a description of its larval stages (Costlow and Bookhout, 1966), post-larval life cycle (Pearce, 1964), studies concerning attraction of adult crabs to hosts (Sastry and Menzel, 1962; Yeater, 1965), and effect of light intensity and temperature on swimming velocity of zoeae (Welsh, 1932). Kruczynski (1972) demonstrated that adult female crabs cause a decrease in growth and dry weight of bay scallops in Bogue Sound, North Carolina.

The object of this study was to determine how the crabs are distributed in scallops in Bogue Sound, and to investigate factors which may control their distribution and abundance.

Materials and Methods

Study area

Bogue Sound is a shallow lagoon approximately 37 km long and 3.7 km wide at its widest point, averaging about 1 m in depth at low tide (Fig. 1). The Intercoastal Waterway closely parallels its north shore and is 6 m deep. Ocean water is supplied through two inlets, one at each end. Fresh water is received from creeks and runoff along its north shore as well as from a river at each end.

Benthic grass (*Zostera* and *Halodule*) is contagiously distributed throughout the sound except in the inland waterway. Scallops are found throughout the sound where grass occurs or was recently abundant.

Zoeae distribution and abundance

Monthly plankton tows were made at eight areas along the length of Bogue Sound from June 1969 to June 1970 (Fig. 1, Sites 1, 3, 4, 7, 8, 10, 12, 13). No plankton samples were taken in October, February and May. Tows were made at night, pulling a plankton net behind a boat moving at "trolling speed" for ten minutes, thus semi-quantifying samples. Surface salinity and temperature were measured while towing. Plankton samples were preserved in formalin and approximate volume of plankton for each tow measured in a graduated cylinder after the manner of Wickstead (1965). An aliquot was examined under a dissecting microscope and zoeae of *P. maculatus* removed and counted. An estimate

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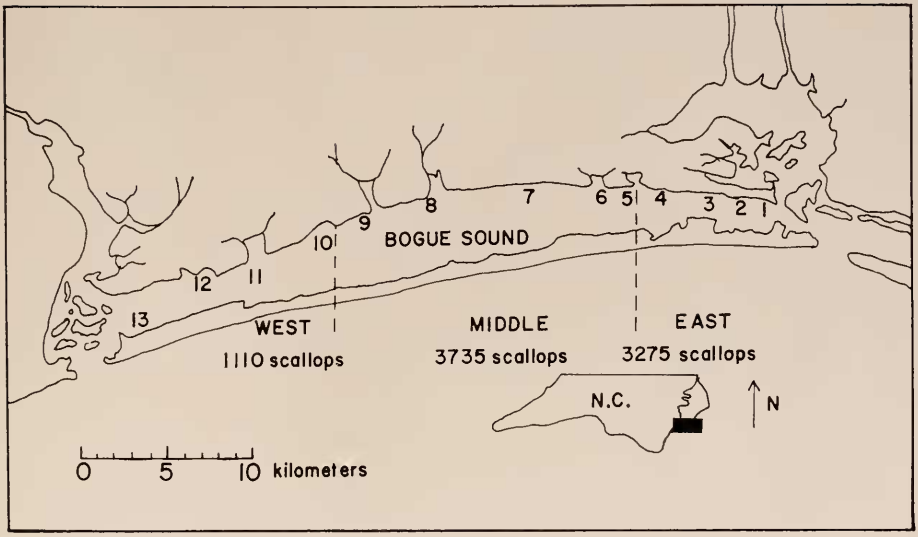

FIGURE 1. Collection sites in Bogue Sound, North Carolina. Sites of plankton collections and salinity measurements are: 1, 3, 4, 7, 8, 10, 12, 13. Sites of quadrat sampling are: 2, 3, 5, 6, 7, 8, 9, 12. Sites of gridded scallop beds are: 3, 4, 7, 8, 9, 10, 12, 13.

of total number of zoeae per tow was made from the ratio picked volume to total volume of sample.

Distribution and abundance of post-larval P. maculatus

Post-larval crabs occur in scallops, so seasonal abundance and distribution of these stages was studied by collecting scallops from various areas in the sound from 1968 to 1970. Scallops were collected by hand or with a small dredge from shallow-water grass beds. Scallops were taken to the laboratory, measured, opened and inspected for crabs. Crabs were measured and life-cycle stage determined. Seminal receptacles of all females were dissected and smear mounts examined for presence of sperm.

Scallop distribution and abundance

The possibility that crab distribution may be controlled by the abundance of scallops arose early in this study and two methods were used to test this theory.

Transects. Eight locations (Fig. 1, Sites 2, 3, 5, 6, 7, 8, 9, 12) where scallops were known to occur were chosen and a series of transects made at each site. All transects ran from low tide mark on the north shore to waist deep water. One-square-meter quadrats were cleared every 5 m and scallops counted. Some scallops were taken back to the laboratory for further examination and crabs were noted. Presence or absence of a grass bottom was recorded for each quadrat.

Grids. To further assess scallop density and total numbers, eight scallop beds were gridded and compared (Fig. 1, Sites 3, 4, 7, 8, 9, 10, 12, 13). These beds

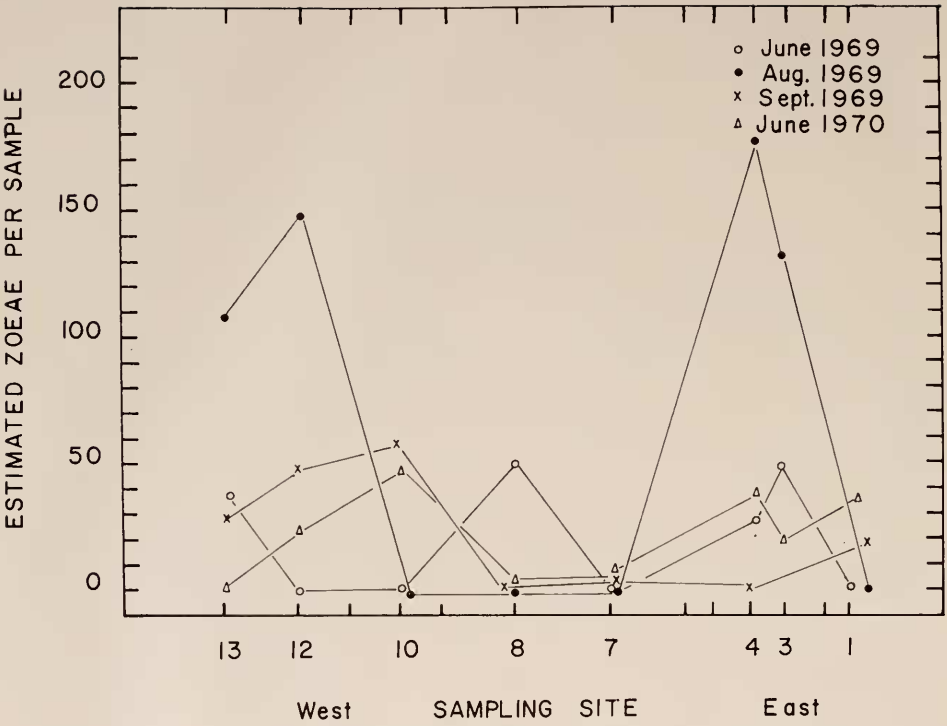

FIGURE 2. Abundance of zoeae of *Pinnotheres maculatus* in Bogue Sound in selected months of 1969 and 1970.

were chosen because scallops were found to occur in good numbers at each site. A portion of each bed was divided into a grid by driving stakes every 25 m along a square. Each staked area enclosed 2500 m². At time of sampling, total grass cover of the gridded area was sketched. A random numbers table was used to fix the center of each sample arc. Samples were made only when this center fell on a grassy area. A circle with a 5 m radius (78 m²), or a half circle (39 m²) was cleared with a scallop rake or by hand around the randomly chosen grassy center. Scallops collected were taken to the laboratory, counted, measured and opened. Crabs were noted. An estimate of the total number of scallops for each gridded area was made by multiplying mean density of scallops by the area covered by grass.

RESULTS

Zoeae distribution and abundance

Zoeae were found from April through September and were most abundant in the east and west ends of the sound in August (Fig. 2). Zoeae were not found from November to March when surface temperature was below 12° C but began to appear in April when surface temperature was above 12° C. Zoeae were scarce in the middle areas of the sound except for one sample collected on 16 June 1969 (Fig. 2, Area 8). No adult crabs were naturally found in this area, however,

two days prior to the tow a wire box which contained 10 scallops, each with an ovigerous female crab, was placed on the grass bed where the plankton tow was made. This was done to determine whether adult female crabs could survive in this area. They did survive and it is probably their zoeae which were captured in the sample since few zoeae were later found after removing this box of infected scallops.

Surface salinity was generally higher near the inlets of Bogue Sound and decreased toward the center (Fig. 3).

Post-larval P. maculatus

Inspection of 8120 scallops collected during all months from 1968 to 1971 revealed the post-larval life cycle of *P. maculatus* in Bogue Sound. All stages were more abundant near inlets and absent from center areas of the sound.

Pre-swarming crabs. The first crab instars were found in scallops abundantly in October and November near the inlets (Sites 1, 2, 3, 4, 5, 6, 11, 12, 13) and multiple infections were common. These crabs remained in scallops for several molts and ranged in carapace width from 1 to 6 mm. One hundred fifty-one pre-swarming crabs (60 female, 85 male) were collected. No females in this stage contained sperm in the seminal receptacles.

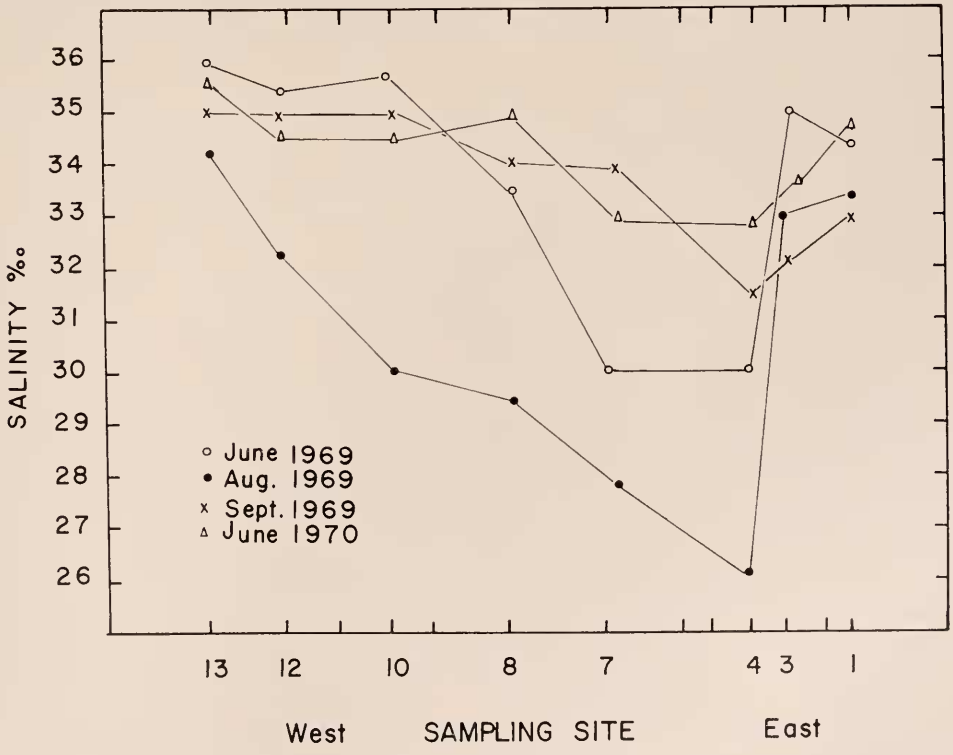

FIGURE 3. Surface salinity at plankton stations.

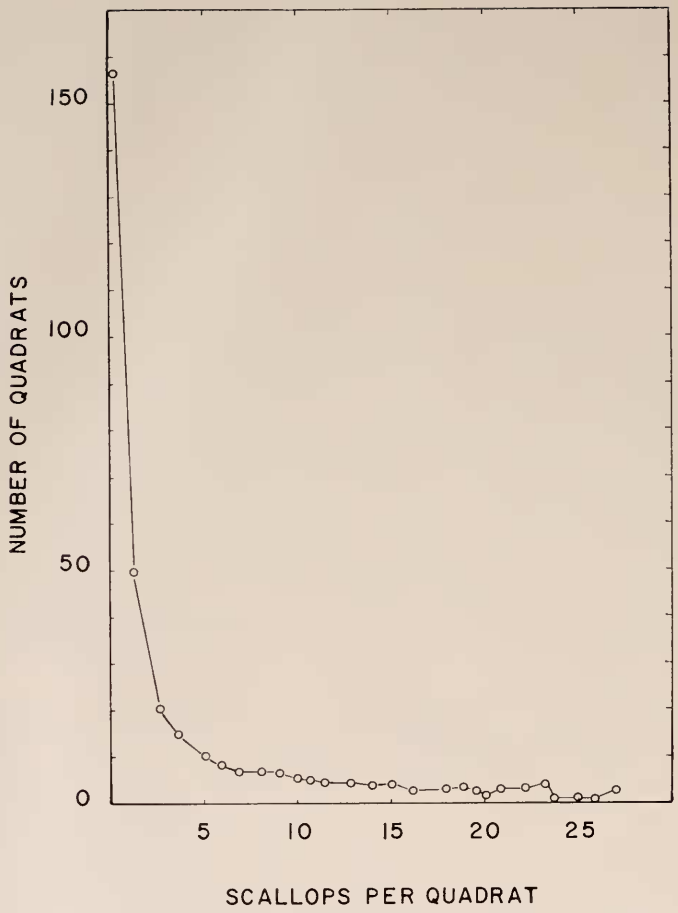

FIGURE 4. Abundance of scallops in quadrats along transect lines.

Swarming crabs. Swarming crabs are specialized for existence in open water and possess swimming hairs on the third, fourth and fifth legs, and are flattened to facilitate entrance into scallops. Swarmers were found in scallops near inlets (Sites 1, 2, 3, 4, 5, 6, 12, 13) in the fall and copulation took place in the open water at this time (this was not observed). Three hundred forty-five (145 female, 200 male) swarmers were collected and they varied in carapace width from 3 to 10 mm. Seminal receptacles of 65% of the swarming females collected in November were found to contain sperm.

Overwintering occurred in either pre-swarming or swarming stage and both stages were found in scallops in March and April. Since some swarmers were found in spring which were not inseminated, it is possible that copulatory swarming may continue in early spring.

Post-swarming crabs. After swarming, males enter scallops and end their life cycle in the swarming stage. They usually accompanied a female crab in scallops

throughout the summer. Females molted into an intermediate stage(s) in which the abdomen was not yet fully developed to carry eggs. Thirty-two intermediates were collected from June through November which ranged in size from 5 to 8 mm in carapace width; all contained sperm. One hundred and sixty-seven ovigerous females were collected from scallops in June through December and ranged from 7 to 14 mm carapace width; all contained sperm. During the summer months only post-swarming crabs were found and only at stations very close to the inlets of the sound (Sites 1, 2, 3, 4, 13). No scallops were found which contained more than one post-swarming female crab.

Seasonal abundance. Seasonal abundance of post-larval stages was followed for various scallop beds. Monthly observations for two years at one area (Site 3), where crabs were most abundant, are summarized below. Ten per cent of 420 scallops collected in June through August contained ovigerous female crabs. Only 6 males were collected and all occurred in a scallop containing an adult female crab. Four hundred and six scallops were collected from September through November and 4% contained ovigerous females, 57% pre-swarming and 42% swarming crabs. In December through February most scallops (about 60 mm shell height) are removed by commercial harvesting, so only 109 scallops were collected during this quarter. No adult females were found, 10% contained pre-swarming crabs, and 6% contained swarming crabs. Scallops collected in March, April and May (210) were predominantly young scallops (25 mm shell height) and contained few pre-swarmers (3%) and swarmers (9%). By June, ovigerous females were found in 9% of scallops (40 mm shell height).

Scallop distribution and abundance

Three hundred thirty-three quadrats were sampled along transects at the eight areas. Frequency of scallops per quadrat fits the negative binomial distribution ($P < 0.05$) which describes positive contagion (Fig. 4). There is a positive correlation (Chi Square $P < 0.05$) of quadrats containing scallops and presence of grass (Table I). Mean scallop density per m^2 was: 2.6, 2.9, 4.3, 3.6, 4.4, 2.5, 1.7, and 2.3; the largest densities found in middle sound, Sites 5, 6 and 7.

Table II summarizes data from gridded areas. Mean density and estimated total numbers were higher for middle sound sites.

Discussion

On the basis of crab distribution in all scallops collected, Bogue Sound can be divided into three areas: East, Middle and West (Fig. 1). Mature female crabs were found only in scallops from east and west sound. All other crab stages were more abundant in these areas, but occurred in marginal middle collections in reduced numbers. Why the crabs are not found in scallops in the middle sound remains an enigma. Scallop density was highest in the mid-sound beds studied by transecting and gridding. Mature female crabs were never found to be really abundant even near the inlets (10%), the most favored areas, so it is unlikely that abundance of hosts controls numbers or distribution of crabs.

Few other studies mention abundance of *P. maculatus* in hosts. Sastry and Menzel (1962) found bay scallops infected with adult females to vary from 13 to

TABLE I

Two-by-two contingency table of quadrat samples along transects at eight sites in Bogue Sound

	Grass	No grass	
Scallops	167	10	177
No scallops	37	119	136
	204	129	333 total quadrats

36% of the total population in Alligator Harbor, Florida. Yeater (1965) found monthly incidence of bay scallops with adult female crabs to vary between 0 and 40% in the same harbor. No females were found in winter months during his study. Pearce (1964) found 97.6% of 1820 *Mytilus edulis* collected at Quicks Hole, Massachusetts, from 5 July 1963 to 5 August 1964, infected with some stage of *P. maculatus.*

I believe the low percentage of adult crab infection in Bogue Sound may be attributed to the commercial scallop fishery which keeps the percentage of scallops infected with post-swarming crabs low. Overwintering crabs are found in great numbers in commercially harvestable scallops. At shucking houses the scallop muscle is saved and shell and viscera discarded near the edge of the sound. Thus, large numbers of pre-adult crabs are killed each winter. However, this theory does not explain why surviving crabs are found only near the inlets of the sound.

Several other cases of geographic variation in host preference and host infection by pinnotherid crabs have been found by Williams and Needham (1939), and Gray (1961). MacGinitie and MacGinitie (1949) found that *Pinnixa eburna* Wells infected tubes of *Arenicola* worms which occurred in sand and were never found with worms in adjacent mud flats. Pearce (1966) found a correlation between water depth at which *Modiolus modiolus* were found and per cent infection by *Fabia subquadrata;* 0 to 20 m depth was optimum for the crab. Crabs taken from mussels in deeper water tended to be smaller. Depth of host animal was also found to be a factor controlling distribution of *Pinnotheres pisum* in mussels (Houghton, 1963; Seed, 1969) and *Pinnotheres ostreum* in oysters (Beach, 1969).

TABLE II

Grass cover, sampling area, scallop density and estimated total scallops of gridded areas

Area	Estimated grass cover-m²	Number samples taken	Total area cleared-m²	Mean density per m²	Estimated total no.
3	1525	3	234	0.6	930
4	1562	3	156	1.4	2250
7	1000	3	156	3.9	3890
8	1050	3	195	2.2	2352
9	900	2	156	2.3	2097
10	1090	2	156	1.2	1305
12	1075	1	78	2.1	2300
13	638	2	117	1.2	733

Per cent infection was observed to be greatest below low tide line, and Beach theorized that the longer the submergence of hosts, the more opportunity for invasion.

Goodbody (1960) suggested that abbreviated development of zoeal stages in *Pinnotheres moseri* Rathbun may be an adaptation preventing larvae from dispersing too far away from concentrations of its host population. No abbreviated development is known to occur in *P. maculatus*. Assuming that tidal currents sweep *P. maculatus* larvae into the middle of Bogue Sound, the fact that adults are not found there suggests that the area does not satisfy the species requirements. Hosts are plentiful, no competition with other animals is known, and there is no evidence of increased predation; therefore some physical or chemical requirements may be lacking. That adults can survive in this area, at least for a short time, has been established, so the limiting factor probably acts on a preadult stage. Surface salinity was the only environmental variable measured in this study. It is possible that pronounced salinity gradients could be produced during times of heavy rains and land runoff.

The effect of salinity on the distribution of the closely allied *Pinnotheres ostreum* is well understood. Beach (1969) found that salinity may exert a marked effect on larval stages of *P. ostreum* because embryonic development is not possible below 15 ‰, although adults could survive lower salinities. Nagabhushanam (1965) found salinity from 6 to 7‰ lethal for adult *P. ostreum* within 24 hours. Stauber (1945) observed death of "hard stage" *P. ostreum* during periods of low salinities whereas female crabs in later stages of development were able to survive these salinities. Flower and McDermott (1952) found a graduated percentage of oysters with crabs along the length of Delaware Bay. Oysters from the lower, more saline waters were infected more than oysters from the upper reaches of the bay. Pinschmidt (1963) described a decrease of *P. ostreum* larvae in upper reaches of the Newport River North Carolina estuary. His findings indicate a net downstream displacement of crab larve because of tides. First stage (invasive) crabs were more numerous in higher salinity waters of the lower estuary.

Read (1968) studied salinity as a potential limiting factor in the distribution of both *P. ostreum* and *P. maculatus*, and determined that *P. maculatus* exhibits good survival at 25° C in only 20 and 30‰ water, and concluded that higher salinities were conducive to its survival. Read also found that *P. maculatus* was a weak osmotic regulator and its body cells were intolerant of low osmotic concentrations; however, because the bay scallop is found in 20 to 38‰, he concluded that *P. maculatus* will be found in all areas inhabited by the scallop. This is clearly not so in Bogue Sound. Walker (1969) showed that *Halicarcinus lacustris* (Chilton), a brackish water crab, can tolerate a wide range of salinity in the laboratory, yet normally occur in a narrow range in Australian inland waters.

Other factors, such as tidal current, could possibly control distribution of the crab in Bogue Sound scallops. The position of certain species can be maintained by selectively using certain stages of tidal current (Verwey, 1960; Stieve, 1961; Hughes, 1969). Such behavior could keep larval or swarming *P. maculatus* near east and west Bogue Sound. I visualize the control of distribution of *P. maculatus* in Bogue Sound as follows: larvae are swept to all reaches of the sound by tidal currents but survive best near inlets. Scallops are invaded in great numbers

in fall and early winter. Heavy rains at this time reinforce the salinity gradient in Bogue Sound. Many pre-swarmers and swarmers are lost because of scallop harvesting. Swarmers receive an external cue and begin a migration on ebb tides becoming concentrated near inlets, or use tides to maintain near-inlet position. Copulation takes place and inseminated females seek a definitive host in the area where copulation occurs.

Studies of the distribution of *P. maculatus* in *M. edulis* in a more northern estuary with a salinity gradient paralleling that in Bogue Sound would be interesting because the mussel has a wide salinity tolerance (10 to 30‰).

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Summary

1. All stages of *Pinnotheres maculatus* were more abundant near the inlets of Bogue Sound, North Carolina.

2. Distribution and abundance of adult crabs did not conform to distribution of scallops, since scallops were numerous throughout the sound.

3. It is possible that crab distribution is controlled by a physical or chemical gradient such as salinity.

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